Quality of Ground Water and Surface Water in an Area of Individual Sewage Disposal System Use Near Barker Reservoir, Nederland, Colorado, August–September 1998

Introduction

Barker Reservoir is a mountain reservoir adjacent to Nederland, Colorado (fig. 1), that supplies 40 percent of the drinking water for the city of Boulder, Colorado. The local geology is quite complex in this region of the Colorado Mineral Belt (Lovering and Goddard, 1950). The study area is primarily Precambrian igneous and metamorphic rock, except for Quaternary alluvium and colluvium in streambeds and drainages that lead to the reservoir (Gable, 1972). The reservoir is fed by North Beaver Creek and Middle Boulder Creek. Ground water that discharges into Barker Reservoir flows beneath residential developments on the north and south sides of the reservoir. Homes on both sides of the reservoir use individual sewage disposal systems (ISDS's) for disposal of domestic wastewater.

ISDS's, also called septic systems, are a common source for reported contamination of ground water (Canter and Knox, 1986). A system that is not properly designed or maintained may leak sewage into surrounding soil, which then can contaminate surface water or ground water. Even properly functioning systems can contribute considerable loads of chemical constituents that are not removed during infiltration (Wilhelm and others, 1994).

ISDS design can vary, but a basic system includes a septic tank and a leach field. Solid and liquid household waste is transported from the residence through a sewage pipe to the tank, where biological processes begin breakdown of the waste. Solid waste that does not liquefy settles in the tank and must be pumped out periodically. Liquid is decanted from the top of the tank and transported to the leach field where it is distributed through perforated pipe or another means to the soil. Liquid waste flows through the soil, undergoing biological and chemical processes as it travels to the water table.

ISDS effluent is composed of the domestic water supply (ground water or municipal water) that has been modified by chemicals introduced by household activities (detergents, cleaning agents, human wastes, and so forth). ISDS treatment reduces the concentrations of water-quality properties such as biological oxygen demand and total suspended solids by physical and biological processes but has little effect on many chemical constituents such as dissolved ions like sodium and chloride.

The U.S. Geological Survey (USGS), in cooperation with the City of Boulder, Colorado, conducted this study to evaluate whether ISDS's affect the quality of ground water entering Barker Reservoir or its tributaries. This report describes the results of water-quality samples collected in August and September of 1998. Water-quality samples were collected from 12 wells and 10 springs or surface-water drainages near Barker Reservoir.

Data Collection

Residential development on the south side of Barker Reservoir is denser and more established than developments on the north side. As the area south of Barker Reservoir was annexed into the Nederland city limits, homes have been connected to a public water system supplied by Middle Boulder Creek upstream from Barker Reservoir. As homes are connected to the public supply, home owners are required to close their wells. Therefore, only one well was available for sampling and analysis in the area. Six springs and surface-water drainages in the area south of Barker Reservoir were sampled in addition to the well (fig. 1). Springs are point discharges of ground water to the land surface. Streamflow during the late summer generally is contributed by ground-water seepage. Data from springs and streams are often indicative of ground-water quality.

North of Barker Reservoir, residents use wells for drinking water and many wells were available for sampling. However, several of the wells are completed far below the water table and may not represent shallow ground water. Therefore, not all of the available wells were sampled, and some wells included in the study may be too deep to show ISDS influence. Eleven wells, three springs, and one drainage site were sampled north of Barker Reservoir (fig. 1).

Water-quality samples were collected from surface- and ground-water sites. Grab samples were collected from small streams and springs during base flow. Samples from springs were collected as

Surface-water drainage into Barker Reservoir (site D1).

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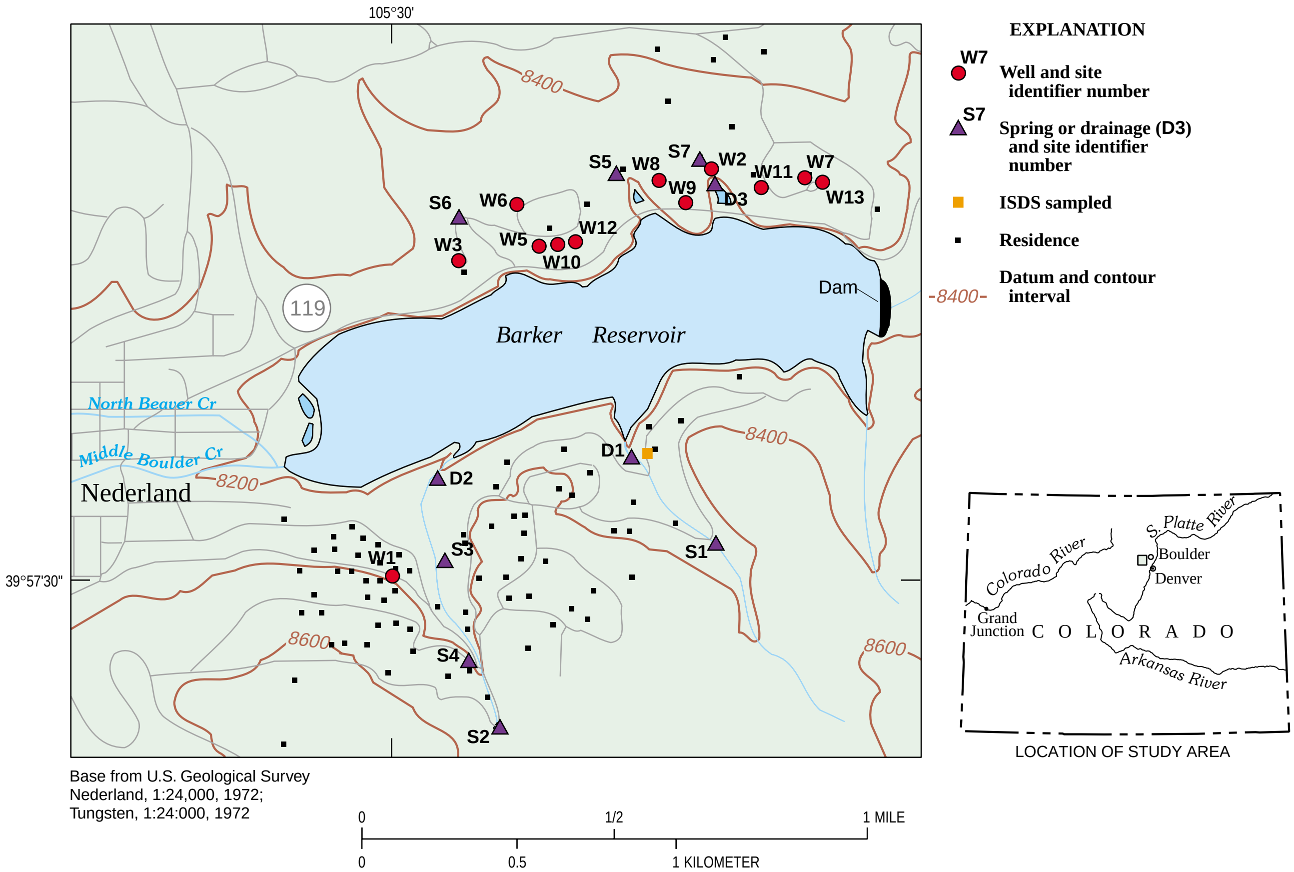

Figure 1. *Study area and sampling-site identifiers.*

close to the source of the ground-water outflow as possible to reflect ground-water quality. Samples from streams were collected where flow was adequate to fill the sample bottles without disturbing sediment. Ground-water samples were collected from domestic wells using the existing pumps installed and used by the home owners. Well information is presented in table 1. When possible, well samples were collected at a point in the system before treatment or storage. If it was not possible to collect a sample at a point before a storage tank, the tank was drained before the sample was collected. At least one casing volume, estimated on the basis of well depth and diameter, if known, was purged from the well before sampling. Some of the flow was diverted through clean polyethylene tubing to an open flow-through chamber where field measurements were made for pH, temperature, specific conductance, and dissolved oxygen. When field measurements were stable (three measurements with less than 10 percent difference over 30 minutes), the ground-water sample was collected. An aliquot of sample water was titrated in the field to determine alkalinity. Samples for analysis of dissolved constituents were filtered through a 0.45-µm capsule filter. Samples for cation analysis were acidified with nitric acid, and all samples were stored on ice until delivery to the appropriate laboratory for analysis.

Water-quality results are presented in table 2. Water-quality samples from locations hydrologically upgradient from local contaminant sources commonly indicate ambient water-quality conditions in an area. Comparisons between upgradient and downgradient samples can help identify the effects of local contaminant sources. Sites S1 and S2 are springfed streamflows that are upgradient from the development around

Table 1. Well information

[ID, identifier; bls, below land surface; >, greater than; --, data not available]

Site ID	Water level (feet bls)	Screened intervals (feet bls)	Well depth (feet bls)[1]	Well construction log available
W1	22.9	unknown	100	no
W2	--	unknown	250	no
W3	71.3	unknown	170	no
W5	136.9	190–210 230–250 270–350	360	yes
W6	--	440–500	500	yes
W7	--	170–190 230–250 290–310 350–430	440	yes
W8	127.8	unknown	365	no
W9	109.4	245–325	325	yes
W10	--	unknown	320	no
W11	--	unknown	unknown	no
W12	--	unknown	180	no
W13	--	unknown	>300	no

[1]If well construction log is not available, well depth is an estimate from the well owner.

Barker Reservoir (fig. 1). Site S2, however, does not appear to be a pristine site; there is evidence of previous structures near the sample-collection point.

Water-quality constituents that can indicate contamination from septic systems include boron, nitrate, phosphorus, fecal coliform bacteria, and total organic carbon (TOC) (Canter and Knox, 1986; Barber and others, 1988; Wilhelm and others, 1994; Barber and others, 1997). All are possible products of consumption of commercial products or human waste that would be disposed of in an ISDS.

Water levels were measured when possible (table 1). It was not possible to measure water levels at many wells because the measuring tape would not fit down the well with the electrical wiring for the domestic pump.

Individual Sewage Disposal System

One ISDS was sampled during this study, and analyses were done by the City of Boulder wastewater laboratory (table 2). The sample was collected by dipping a collection bottle into the liquid in the septic tank and pouring that liquid into sample bottles. The result for boron analysis for the ISDS was performed but was considered unreliable by the laboratory. Although it is informative to compare the results to the ground-water and surface-water analyses, this one system may not be representative of other ISDS's in the area.

Quality Assurance/Quality Control

Duplicates and field blanks were collected at sites S4 and W5 to evaluate precision of laboratory analysis and field procedures (table 2). The duplicate analysis data were acceptable for all analyses. The bacteria duplicate sample at S4 was significantly different than the sample, but the difference was exaggerated by the low number of colonies (5 and 9 colonies per 100 milliliters). A blank sample is a sample bottle filled in the field with deionized water instead of sample water. Field-blank data were acceptable for all analyses.

Sample collection from a domestic well.

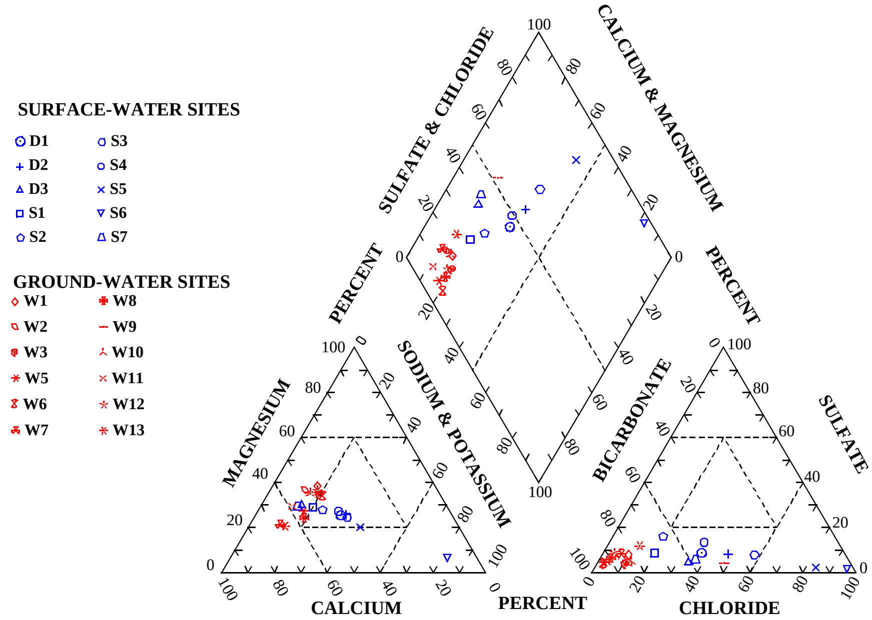

Figure 2. *Piper trilinear diagram.*

Water Quality

A Piper trilinear diagram was plotted for the sites discussed in this report (fig. 2). A Piper diagram is a plot that provides a visual representation of the concentrations of major ions in water (Hem, 1992). This diagram can be useful for looking at similarities and differences among water samples. Bar graphs are presented for boron (fig. 3), nitrate and ammonia nitrogen (fig. 4), dissolved phosphorus and dissolved orthophosphorus (fig. 5), fecal coliform bacteria (fig. 6), TOC (fig. 7), and specific ultraviolet absorbance (fig. 8) for the sites discussed in this report.

Major Ions

Many of the wells are clustered together on the diagram, indicating that they are similar in ion ratios. The Piper plot indicates that for most of the wells, the predominant ions in the ground-water samples were calcium and bicarbonate. Generally, most ground-water samples had smaller concentrations of sulfate and chloride than surface-water sites. Analyses from surface-water sites were less uniform and had a larger percentage of chloride than ground-water sites. Large chloride concentrations in surface water (table 2) possibly were a result of runoff from roads to which salts have been applied. Site S6 had high percentages of sodium and chloride; its ion ratio was not similar to any other sample in this study (table 2). Sites S1 and S2 are surface-water sites upgradient from roads and development and had lower chloride concentrations than other surface-water sites. The ISDS was not included on the Piper diagram because the ion analysis was incomplete.

Boron

Boron is potentially a good indicator of ISDS effects on ground water because (1) natural background concentrations are generally low relative to ISDS effluent, (2) boron does not undergo biological removal during treatment, and (3) boron is not significantly sorbed in the subsurface (Barber and others, 1988). Boron concentrations in surface water and ground water of the Colorado Front Range typically range from less than 10 µg/L (micrograms per liter) to 40 µg/L (Barnett and others, 1969). Elevated boron concentrations can indicate human influence. Anthropogenic sources of boron include non-chlorine bleaches and fruit (Waggott, 1969).

Most of the ground-water sites have boron concentrations of less than 20 µg/L (fig. 3). Site S1, one of two surface-water sites where boron was below the reporting limit, is a spring upgradient from residential development. The other surface-water site where boron was below the reporting limit was S7, a spring upgradient from site D3, where the boron concentration was 31.9 µg/L. The boron concentrations in samples from sites S2, S3, S4, and D2 were greater than expected background concentrations of 10 to 40 µg/L. The source of boron at these sites is unknown, but could be near site S2. The sample for site S2 was collected as close to the source as feasible, but the spring source was inaccessible beneath a concrete and metal structure. The concentration for

Table 2. Selected water-quality data for surface-water and ground-water sites near Barker Reservoir, August–September 1998

[˚C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L milligrams per liter; NTU, nephelometric turbidity units; $CaCO_3$, calcium carbonate; HCO_3^-, bicarbonate; mL, milliliter; µg/L, micrograms per liter; nm, nanometer; <, less than detection limit; location of sites shown in figure 1]

Constituent or property (units)	Reporting limit[1]	D1	D2	D3	S1	S2	S3	S4	S4 duplicate	S4 blank	S5	S6	S7	W1	W2	W3	W5	W5 duplicate	W5 blank	W6	W7	W8	W9	W10	W11	W12	W13	ISDS[2]
Date (month and day) 1998	--	08/18	08/24	08/25	08/17	08/18	08/19	08/19	08/19	08/19	08/24	08/26	08/31	08/20	08/25	08/26	08/27	08/27	08/27	08/31	09/01	09/01	09/02	09/02	09/08	09/08	09/09	--
Time	--	1025	1000	1115	1035	1305	1105	1310	1315	1350	1320	1155	1315	1045	1040	945	1130	1140	1200	1029	1010	1345	1015	1315	1020	1305	1315	--
Temperature (˚C)	--	11.2	10.3	12.0	11.9	7.7	10.2	7.2	--	--	8.0	17.0	11.2	9.9	9.6	9.5	10.3	--	--	12.1	9.1	12.3	11.5	13.7	9.3	10.3	9.4	--
pH—field (pH units)	--	7.8	7.8	7.9	6.6	7.2	6.4	6.7	--	--	6.5	6.7	6.5	7.1	7.2	6.5	7.1	--	--	6.5	7.6	7.1	6.3	6.8	7.3	6.7	7.1	--
pH—lab (pH units)	0.1	7.4	8.0	7.9	6.8	7.2	6.6	6.6	6.6	6.9	6.6	7.0	6.9	7.1	7.3	6.6	7.1	7.1	7.4	6.7	7.8	7.2	6.4	6.8	7.3	7.0	7.1	--
Specific conductance—field (µS/cm)	--	220	315	414	137	245	345	228	--	--	758	2,620	396	266	548	226	286	--	--	197	384	448	415	302	385	231	484	--
Specific conductance—lab (µS/cm)	1.0	218	312	412	136	248	341	226	227	1.46	741	2,850	390	266	542	221	284	282	1.83	200	385	447	412	311	400	231	486	--
Dissolved oxygen—field (mg/L)	--	8.4	8.4	7.9	5.7	8.4	6.4	7.6	--	--	7.4	6.4	4.0	5.6	5.2	1.4	0.3	--	--	3.7	1.7	1.5	6.4	3.8	5.3	2.2	5.3	--
Turbidity—field (NTU)	--	207.0	11.3	21.0	1.7	33.6	10.9	17.7	--	--	0.5	1.9	6.3	33.0	95	8.2	3.2	--	--	8.3	1.9	36.6	42.2	84.4	1.1	29.1	1.7	--
Alkalinity—field (mg/L as $CaCO_3$)	--	50	56	113	40	68	46	44	--	--	41	27	97	93	228	87	131	--	--	89	155	211	92	121	184	101	156	--
Alkalinity—lab (mg/L as $CaCO_3$)	1.0	47	65	110	51	81	56	55	55	1.4	48	29	110	100	240	88	140	140	1.6	97	170	210	90	140	200	99	160	180
Bicarbonate—field (mg/L as HCO_3^-)	--	61	68	138	49	83	56	54	--	--	50	33	118	113	278	106	160	--	--	109	189	257	112	148	224	123	190	--
Fecal coliform bacteria (number colonies per 100 mL)	--	280	27	101	0	6	32	9	5	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	--
Dissolved ammonia, nitrogen (mg/L)	0.02	0.08	< 0.02	0.49	0.05	0.07	0.07	0.06	0.07	0.06	<0.02	< 0.02	0.04	0.06	<0.02	<0.02	<0.02	<0.02	<0.02	0.03	0.03	0.03	0.04	0.02	0.02	0.03	0.05	29
Dissolved nitrite-nitrogen (mg/L)	0.01	0.02	< 0.01	0.15	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	< 0.01	<0.01	< 0.01	0.002
Dissolved nitrite plus nitrate (mg/L)	0.05	2.3	2.5	1.9	< 0.05	0.14	1.9	1.8	1.8	<0.05	4.8	0.07	1.3	2.4	<0.05	0.81	<0.05	<0.05	<0.05	<0.05	1.3	0.39	<0.05	<0.05	< 0.05	<0.05	9.3	3.1
Total ammonia nitrogen and organic nitrogen (mg/L)	0.1	0.4	0.1	0.9	< 0.1	0.1	0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dissolved ammonia, nitrogen and organic nitrogen (mg/L)	0.1	0.2	0.1	0.6	< 0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	31.46
Total phosphorus (mg/L)	0.01	0.06	< 0.01	0.22	< 0.01	0.03	<0.01	0.03	0.03	<0.01	<0.01	<0.01	<0.01	--	--	--	--	--	--	--	--	--	--	--	--	--	--	19.2
Dissolved phosphorus (mg/L)	0.01	< 0.01	0.01	0.15	< 0.01	<0.01	<0.01	0.03	0.04	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	< 0.01	<0.01	--
Dissolved orthophosphorus (mg/L)	0.01	0.01	0.01	0.15	0.01	0.02	0.02	0.04	0.04	0.02	0.01	<0.01	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	< 0.01	< 0.01	<0.01	20.1 (total)
Total hardness (mg/L as $CaCO_3$)	--	67	93	160	52	91	98	72	73	--	180	200	160	110	250	86	120	120	--	78	170	180	150	130	170	90	200	--
Dissolved calcium (mg/L)	0.02	17	23	42	13	23	24	18	18	< 0.02	48	51	41	25	57	20	31	31	<0.02	18	51	52	34	30	47	20	62	10.264
Dissolved magnesium (mg/L)	0.004	6.1	8.8	14	4.6	8.1	9.0	6.9	6.9	<0.004	16	17	13	13	25	9.1	9.4	9.4	<0.004	8.2	9.9	14	16	13	14	9.8	12	1.377
Dissolved sodium (mg/L)	0.06	13	20	11	5.0	11	22	13	13	< 0.10	60	420	10	9.2	16	8.6	10	10	<0.10	8.3	8.9	18	13	10	9.6	7.7	13	26.553
Dissolved sodium adsorption ratio	--	0.7	0.9	0.4	0.3	0.5	1	0.6	0.7	--	2	13	0.4	0.4	0.4	0.4	0.4	0.4	--	0.4	0.3	0.6	0.5	0.4	0.3	0.4	0.4	--
Dissolved sodium, percent	--	29	32	13	17	20	32	27	27	--	41	82	13	15	12	18	16	16	--	19	11	18	16	15	11	16	13	--
Dissolved potassium (mg/L)	0.1	2.7	3.5	3.6	1.7	4.6	4.0	3.3	3.4	<0.1	4.2	6.6	2.8	2.6	2.9	2.0	1.8	2.0	<0.1	2.2	2.0	3.1	1.7	2.0	2.2	2.5	2.4	0.087
Dissolved chloride (mg/L)	0.1	24	40	44	7.4	14	55	22	22	<0.1	170	720	43	7.1	22	7.2	1.2	1.1	<0.1	0.79	6.3	5.4	64	12	2.3	2.6	17	--
Dissolved sulfate (mg/L)	0.1	7.8	9.4	8.7	4.6	16	10	11	11	< 0.1	6.1	15	9.4	8.5	12	3.9	6.3	6.3	<0.1	3.7	15	14	7.4	6.9	9.1	9.7	23	--
Dissolved fluoride (mg/L)	0.1	0.1	0.1	0.3	0.2	0.1	0.1	0.1	0.1	<0.1	0.1	<0.1	0.3	0.4	0.7	0.3	0.7	0.7	<0.1	0.4	2	0.8	0.6	0.6	1	0.5	0.6	--
Dissolved silica (mg/L)	0.05	16	18	18	21	18	18	20	20	0.24	22	20	18	23	17	28	32	32	0.16	31	13	18	26	30	22	32	19	--
Dissolved iron (µg/L)	10	29	< 10	< 10	46	53	<10	<10	< 10	<10	<10	< 30	800	140	< 10	760	510	520	<10	540	<10	170	1,400	67	230	4,200	<10	0.98
Dissolved boron (µg/L)	16	34.3	68.7	31.9	< 16.0	70.2	74.8	65.6	67.9	<16.0	258	32.6	< 16.0	58.7	< 16.0	< 16.0	< 16.0	< 16.0	<16.0	<16.0	<16.0	20.5	<16.0	<16.0	< 16.0	< 16.0	284	--
Dissolved manganese (µg/L)	4.0	19	< 4.0	< 4.0	17	44	< 4.0	<4.0	< 4.0	<4.0	<4.0	<12	160	56	12	350	56	57	<4.0	160	9.0	130	870	40	27	170	<4.0	0.018
Dissolved solids, residue at 180˚C (mg/L)	10	141	186	238	99.0	154	216	153	145	<10.0	451	1350	234	168	286	138	172	176	<10.0	132	222	263	244	195	243	161	309	--
Total organic carbon (mg/L)	0.2	3.6	2.6	2.4	2.3	1.6	2.0	1.4	1.5	0.2	1.2	1.9	1.9	0.9	0.6	0.4	0.2	0.2	0.3	0.2	0.8	0.6	0.4	0.2	0.5	0.4	1.3	58
UV absorbance at 254 nm	0.001	0.259	0.081	0.061	0.068	0.036	0.067	0.036	0.037	0.004	0.028	0.049	0.077	0.021	0.011	0.010	0.010	0.008	0.005	0.006	0.013	0.01	0.011	0.009	0.013	0.015	0.026	1.34
Specific UV absorbance (uv254/TOC)	--	0.072	0.031	0.025	0.030	0.023	0.033	0.026	0.024	0.016	0.024	0.026	0.040	0.023	0.019	0.026	0.042	0.041	0.018	0.029	0.016	0.018	0.028	0.036	0.027	0.041	0.020	0.023
Fluorescence, raw	--	15.3	13.8	14.7	10.4	5.72	--	5.09	5.11	0.347	5.24	9.47	9.33	3.04	1.87	0.938	0.839	0.474	0.146	0.190	2.02	1.36	0.506	0.325	1.01	0.814	3.74	58
Fluorescence, C18	--	16.0	13.5	14.3	10.8	5.65	9.73	4.92	4.88	0.415	5.00	9.14	9.56	2.98	1.73	0.862	0.804	0.395	0.130	0.145	1.96	1.29	0.475	0.276	0.981	0.656	3.29	48
Fluorescence, percent change	--	–4.6	2.2	2.8	–20	3.0	--	3.3	4.4	–3.6	4.7	3.5	–2.5	2.0	7.4	8.1	4.1	16.5	11	24	3.3	5.2	6.2	15	2.5	19	12	16

[1]U.S. Geological Survey National Water Quality Laboratory world wide web page (http://wwwnwql.cr.usgs.gov/).

[2]ISDS ion and nutrient analyses were performed by the City of Boulder wastewater laboratory; all values are total rather than dissolved, except as noted.

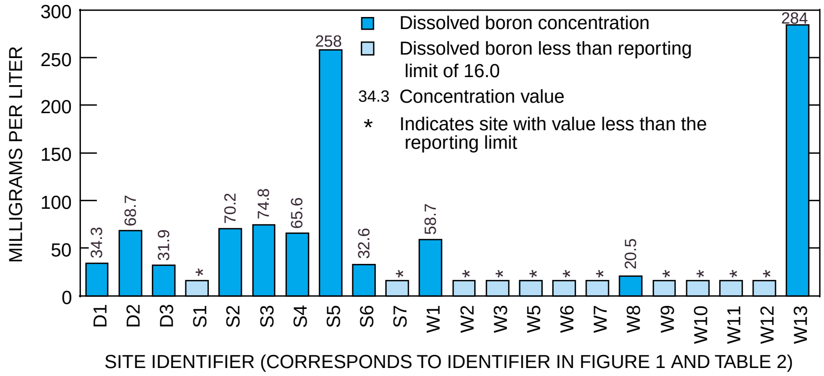

***Figure 3.** Dissolved boron concentrations in ground water and surface water.*

well W1, which is not directly downgradient from site S2, was 58.7 µg/L. Concentrations of boron at sites S5 and W13 were 258 µg/L and 284 µg/L, respectively, indicating possible ISDS influence.

Nutrients

Nutrient analysis is the measurement of different forms of nitrogen and phosphorus in water. Nutrients are a concern in surface water because of eutrophication. In drinking water, including ground water, excess nutrients are a human health concern. The maximum contaminant level (MCL) in finished drinking water for nitrate is 10 milligrams per liter (mg/L) (U.S. Environmental Protection Agency, 1994). The median nitrate concentration from 30 ground-water sites in Boulder County in 1996 was 0.37 mg/L (Bruce and O'Riley, 1997). Sources of nitrogen include organic nitrogen (which is mineralized to nitrate) and fertilizers. Ammonia nitrogen that is applied at the surface in fertilizers or is output from an ISDS is usually converted by nitrification to ionic nitrate in the soil (Freeze and Cherry, 1979). Nitrate can be useful as a tracking tool for ISDS contamination because large concentrations can be contributed by human waste, and nitrate is mobile in water. Analysis was done at all sites in this study for nitrite plus nitrate (table 2). The nitrite concentrations were so small that the results of this analysis are referred to as nitrate in this report. Five wells had nitrate concentrations greater than the reporting limit of 0.05 mg/L and greater than the 1996 median of 0.37 mg/L (fig. 4); wells W1 and W13 had large concentrations of nitrate (2.4 and 9.3 mg/L), possibly indicating an anthropogenic source. These wells also had greater boron concentrations than the other wells. The nitrate concentrations were greater at surface-water sites S3, S4, and D2 (1.9, 1.8, and 2.5 mg/L, respectively) than in the upgradient S2 (0.14 mg/L); greater in D1 (2.3 mg/L) than in upgradient S1 (< 0.05 mg/L); and greater in D3 (1.9 mg/L) than in upgradient S7 (1.3 mg/L). The largest nitrate concentration in a surface-water sample was from site S5 (4.8 mg/L). Concentrations of nitrate were greater than ammonia nitrogen in all of the samples except the ISDS. The nitrogen in the ISDS is in the form of ammonia rather than nitrate because the sample was collected before discharge to the soil, where nitrification occurs.

Phosphorus, which is an ingredient in detergents and cleaners, also can be an indicator of septic contamination. Orthophosphorus is the major inorganic form of phosphorus. The ISDS had considerable concentrations of dissolved phosphorus and dissolved orthophosphorus (19.2 and 20.1 mg/L). The phosphorus concentrations were not substantial for most other sites (fig. 5), possibly because phosphorus is readily removed in the subsurface by sorption and precipitation (Canter and Knox, 1986; Hem, 1992). Phosphorus was not detected at significant concentrations in the wells and springs with the greatest concentrations of boron and nitrate. The largest dissolved phosphorus concentrations were found at sites D3 (0.15 mg/L) and S4 (0.03 mg/L). Site D3 (0.15 mg/L) was the only site, aside from the ISDS (20.1 mg/L), with an orthophosphorus concentration greater than 0.05 mg/L.

Bacteria

Fecal coliform bacteria are present in human and animal wastes. Fecal coliform were not detected in any well north of Barker Reservoir but were detected at surface-water site D3 (fig. 6). Fecal coliform bacteria were detected at many of the surface-water sites south of Barker Reservoir; the largest concentration was at site D1. Wild or domestic animals might be contributing to the fecal coliform concentrations in surface water, such as that in

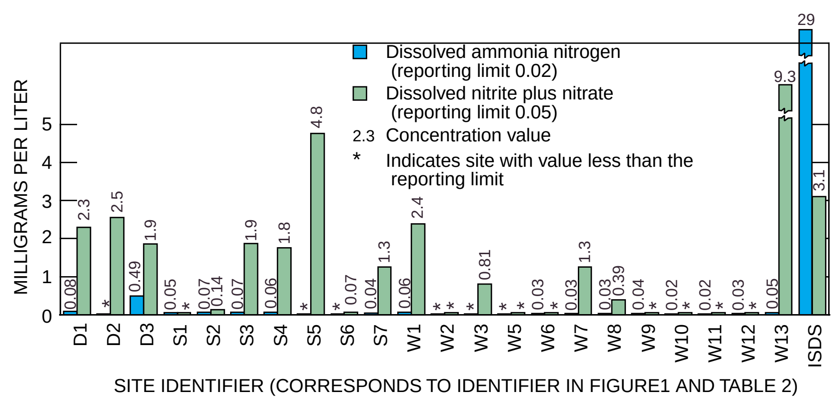

***Figure 4.** Dissolved nitrite plus nitrate and dissolved ammonia nitrogen concentrations in ground water and surface water.*

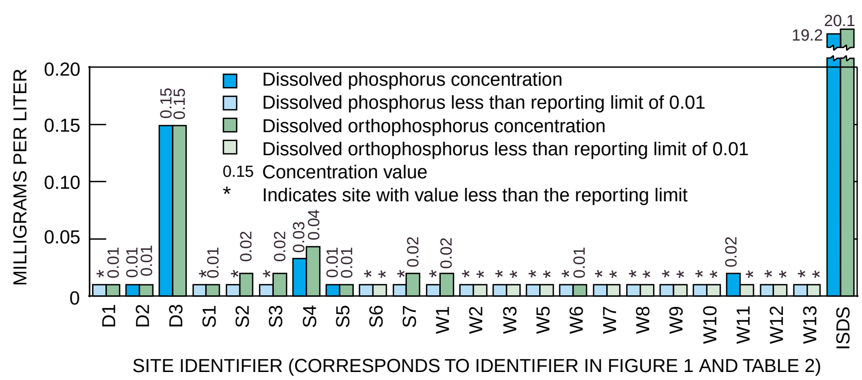

***Figure 5.** Dissolved phosphorus and dissolved orthophosphorus concentrations in ground water and surface water.*

the upgradient surface-water site S2. However, site D1 is downgradient from several ISDS's; thus, it is possible that the contamination is from residential sources. The fecal coliform, boron, and nitrate concentrations for site D1 are all greater than those for the upgradient site S1. The fecal coliform from W1, the only well sampled south of Barker Reservoir, is possibly from anthropogenic sources; this also is indicated by the concentration of boron and nitrate.

A fecal coliform sample was not collected from the ISDS because it was presumed that the number of colonies would be too high for the laboratory to analyze. Fecal coliform in ISDS's can range from 420,000 to 5,000,000 colonies per 100 milliliters (Canter and Knox, 1986). Subsurface transport is an effective removal process for bacteria but not for nitrate and boron, as indicated by the absence of bacteria in the well with the large concentrations of nitrate and boron (W13).

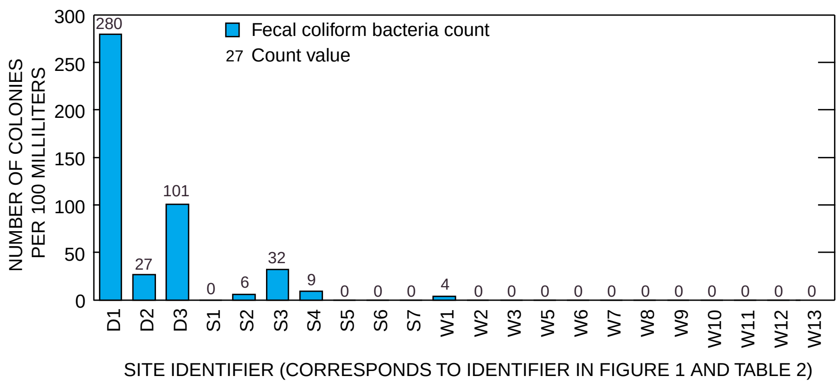

Figure 6. *Fecal coliform bacteria number in ground water and surface water.*

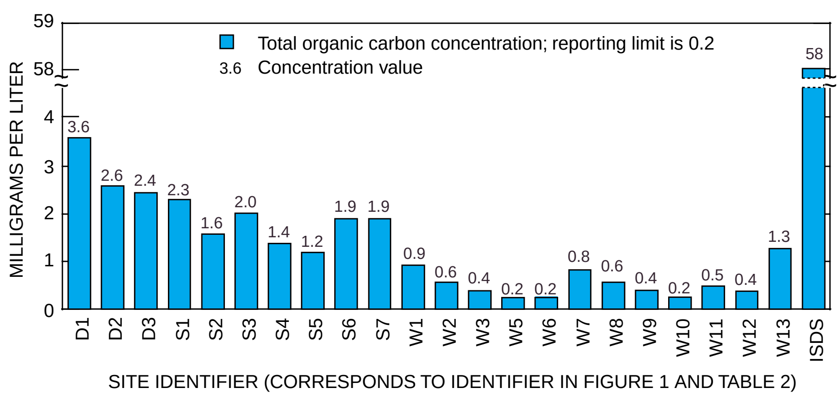

Figure 7. *Total organic carbon (TOC) concentrations in ground water and surface water.*

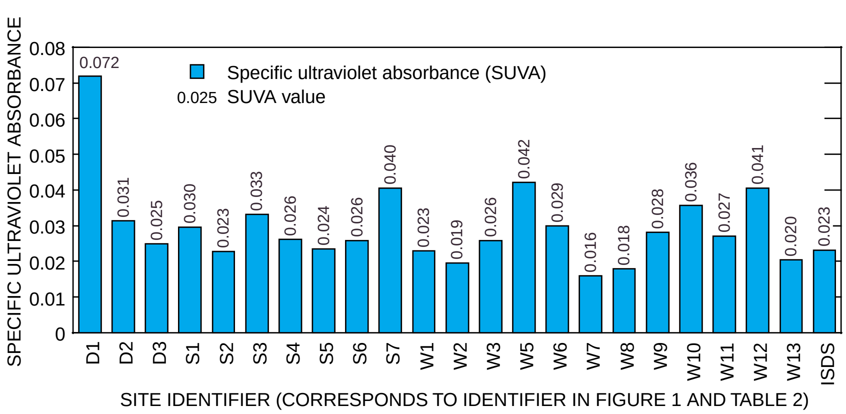

Figure 8. *Specific ultraviolet absorbance (uv254/TOC) in ground water and surface water.*

Total Organic Carbon

Total organic carbon (TOC) is a measurement of all forms of organic carbon present in a water sample. Ground-water concentrations are typically lower than surface-water concentrations because of biodegradation and soil adsorption of organic material during aquifer recharge and because of leaching of plant-derived soil organic matter into surface water. ISDS effluent is highly enriched in TOC because of the biological wastes containing natural biogenic carbon and synthetic organic compounds used in consumer products. The ISDS sampled in this study had 58 mg/L of TOC (table 2 and fig. 7). Substantial removal of TOC can occur during anaerobic degradation in the septic tank and percolation through the leach field and unsaturated zone. Even with removal, properly functioning ISDS's and wastewater infiltration systems can contribute significant TOC concentrations into ground water (Barber and others, 1988; Wilhelm and others, 1994; Barber and others, 1997).

Most of the surface-water TOC concentrations were greater than the ground-water concentrations, and spring-water concentrations were intermediate (fig. 7). TOC concentrations at the downgradient sites D1, D2, and D3 (3.6, 2.6, and 2.4 mg/L, respectively) were greater than the upgradient sites S1, S2, and S7 (2.3, 1.6, and 1.9 mg/L, respectively) because the flowing water interacts with plant detritus and soil organic matter. The largest ground-water concentrations were at well W1 (0.9 mg/L) south of Barker Reservoir and wells W7 (0.8 mg/L) and W13 (1.3 mg/L) north of Barker Reservoir. Nitrate concentrations at all three of these well sites were relatively high, and boron concentrations at two of these sites (W1 and W13) also were high.

UV Absorbance

Light absorption measurements (ultraviolet light absorbance at 254 nanometers, UV254) can indicate differences in TOC characteristics. The molecular structure of natural organic material has different light absorption properties than those of synthetic detergents. The sulfonated aromatic rings in synthetic detergents absorb less UV light than the phenol-substituted aromatic rings of natural humic substances (J. Leenheer, U.S. Geological Survey, written commun., 1999).

UV absorption measurements are more easily compared when they are normalized by dividing the UV254 by the TOC concentration. This measurement is called specific UV absorbance, or SUVA (fig. 8). An inverse relation between SUVA and septic contamination should exist. The relatively large SUVA reading at site D1 shows the influence of plant and soil organic matter on TOC, whereas

Sample collection from an individual sewage disposal system.

the lower SUVA reading at the ISDS indicates a different TOC source. The spring and ground-water SUVA values are variable and show no obvious trend.

Conclusions

Analyses of ground water north of Barker Reservoir do not indicate widespread contamination, although isolated areas have concentrations of septic indicators such as boron, nitrate, and TOC that are larger than at other areas. The sites that show the greatest concentrations of indicator constituents (for example, S5, W3, W7, and W13) are at residences that are older than the other residences north of Barker Reservoir in this study, and contaminants may have had more time to reach the ground water. Surface-water site D3 had greater concentrations of nitrate, phosphorus, fecal coliform, and TOC than upgradient site S7.

South of Barker Reservoir, downgradient surface-water sites (D1, D2, S3, and S4) had greater concentrations of some constituents than upgradient surface-water sites (S1 and S2). The contamination could be from runoff in the area or from wildlife and domestic animals but also could indicate ISDS contamination. Ground-water data are limited south of the reservoir, with only one relatively shallow well to sample (well W1). Concentrations of nitrate, boron, fecal coliform, and TOC at this site were suggestive of possible ISDS effects. Data from more wells are needed to determine the extent and magnitude of ground-water contamination.

This study had a limited analyte list of a few indicator compounds. ISDS effluents are very complex, and the presence of indicator compounds might indicate that other potentially detrimental compounds also may be present.

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